Experiments to Probe Quantum Linearity with Massive Nanoparticles

Markus Arndt, University of Vienna, Faculty of Physics, QNP Group
Boltzmanngasse 5, A- 1090 Vienna, Austria

Quantum physics is the best-confirmed theory of nature, and yet important questions have remained open: Why do we find unitary evolution in quantum mechanics but not in the macroscopic world we live in? What defines the cut between coherent superpositions of quantum states and seemingly irreversible measurements among many mutually exclusive possibilities? These questions have been guiding our research on nanoparticle interferometer and control schemes[1]. We were able to demonstrate the quantum wave nature of fullerenes, vitamins[2], polypeptide antibiotics and macromolecules up to 10'000 amu[3], and in all experiments so far, quantum mechanics was confirmed and clearly distinct from a classical world view. In an ongoing effort to prepare novel quantum experiments between $10^4 - 10^6$ amu we have established a new long-baseline matter-wave interferometer that can cope with de Broglie wavelengths even below 100 fm. In an effort to push the mass limit by even another two orders of magnitude, to between 10^6-10^8 amu, we are advancing nanoparticle cavity optomechanics. This includes methods to launch and detect high-mass silicon nanorods[4] and new microcavities[5, 6] that strongly couple these nanoparticles to intense light fields. The combination shall enable cooling to 5D quantum states, for novel tests at the quantum-classical interface[7].

1. Arndt M, Hornberger K. Insight review: Testing the limits of quantum mechanical superpositions. ***Nature Phys*** **10**, 271-277 (2014).
2. Mairhofer L, Eibenberger S, Cotter JP, Romirer M, Shayeghi A, Arndt M. Quantum-assisted metrology of neutral vitamins in the gas phase. ***Angew Chem Int Ed*** **56**, 10947 - 10951 (2017).
3. Eibenberger S, Gerlich S, Arndt M, Mayor M, Tüxen J. Matter-wave interference of particles selected from a molecular library with masses exceeding 10 000 amu. ***Phys Chem Chem Phys*** **15**, 14696 - 14700 (2013).
4. Asenbaum P, Kuhn S, Nimmrichter S, Sezer U, Arndt M. Cavity cooling of free silicon nanoparticles in high-vacuum ***Nature Communications*** **4,** 2743 (2013).
5. Stickler BA, Nimmrichter S, Martinetz L, Kuhn S, Arndt M, Hornberger K. Rotranslational cavity cooling of dielectric rods and disks. ***Phys Rev A*** **94**, 033818 (2016).
6. Kuhn S*, et al.* Cavity-assisted manipulation of freely rotating silicon nanorods in high vacuum. ***Nano Lett*** **15**, 5604−5608 (2015).
7. Stickler BA, Papendell B, Kuhn S, Millen J, Arndt M, Hornberger K. Orientational quantum revivals of nanoscale rotors. ***arXiv:180301778v1*** **(**2018).